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THE ROLE OF MULTI-SCALE FINITE ELEMENT METHODS IN ANALYSIS AND DESIGN OF ADVANCED MECHANICAL AND AEROSPACE STRUCTURES

STELIOS K. GEORGANTZINOS

Metallic Structures Laboratory, National and Kapodistrian University of Athens, Psachna, Greece

ABSTRACT

The fast rise of nanotechnology and the corresponding discovery of novel nanomaterials and nanostructures have attracted the attention of the research, scientific, as well as business community for finding possible effective solutions in challenging problems of human everyday life. The key point of this attention is based mainly on the combination of superior mechanical, electrical, thermal and generally physical performance of nanostructures, as well as their light weight. In our days, it is well accepted that computational techniques, and specifically multi-scale finite element methods, have a leading role in the analysis and design process. Its multi physics nature makes it an ideal candidate for an efficient design tool of advanced mechanical and aerospace structures.

***KEYWORDS:** Nanotechnology, Multi-Scale Finite Element Methods & Aerospace Structures*

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Original Article

INTRODUCTION

In recent years, the fast rise of nanotechnology and the corresponding discovery of novel nanomaterials and nanostructures, such as carbon nanotubes [1] and graphene [2], have attracted the attention of the research, scientific, as well as business community for finding possible effective solutions in challenging problems of human everyday life. The key point of this attention is based mainly on the combination of superior mechanical, electrical, thermal and generally physical performance of nanostructures, as well as their light weight. Therefore, the main issue is focused on the way of taking advantage of those excellent properties and performance developing new applications.

An idea is the re-design of traditional structures, machines, systems or devices taking into account the addition of nanostructures in them, via an efficient way. By this concept, an expected outcome is, for example, a general significant improvement of specific properties of a conventional mechanical or aerospace structural component. Another challenging idea is the building of traditional structures or systems in smaller scales, i. e. micro or nano-scale, using nanostructures as building blocks. Otherwise, the miniaturization of products is a general goal of science and engineering [3]. Finally, the development of innovative products that they are able to be produced due to the novel properties of nanostructures, of course, constitutes an obvious objective.

FEM IN DESIGN PROCESS

The previously mentioned ideas are, really, pure engineering design problems, for which typical engineering design steps, such as conceptual design, preliminary design, detailed design etc. might be implemented.

Basic steps in the design process are the analysis, synthesis and optimization. Those can be supported by experiments, analytical and/or computational/numerical techniques, depending on the nature of the problem. In our days, it is well accepted that computational techniques, and specifically the Finite Element Method (FEM), have a leading role in the analysis and design process [4]. The main advantage of FEM is that it can encounter any engineering problem by a highly accurate and, also, a cost-effective way. Given the fact that nanomaterials and nanostructures are characterized by their multi-functionality, the multi-physics nature of FEM makes it an ideal candidate for a design tool in nano-technological applications (Figure 1).

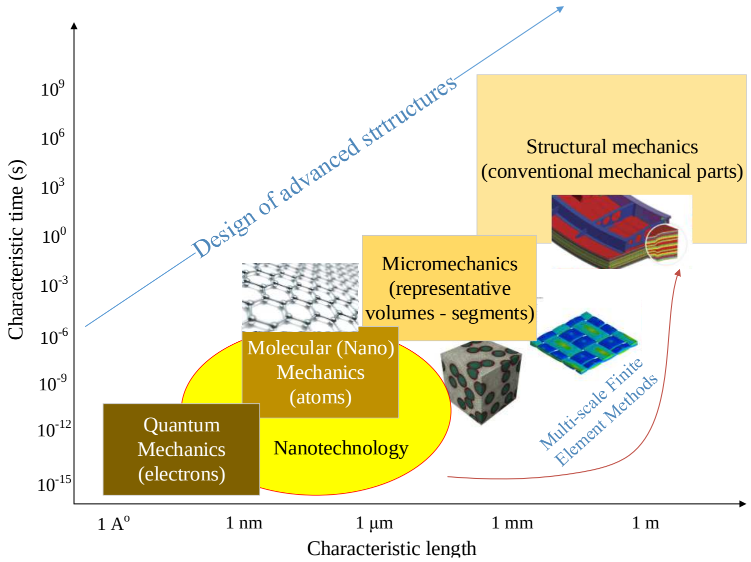

Figure 1: Length and Time Scales in Engineering Design and the Usage of FEM

Its role becomes more significant in the field of nanotechnology, since the experimentation in nano-scale involves a relatively high cost, while analytical methods are difficult to be established. However, why someone have to prefer FEM from Molecular Dynamics (MD), which is a classical computational method for problems in nano-scale? The answer is simple and is based on the computational cost. Since MD is a dynamics method, a static problem has to be treated dynamically, and this means much more computational time for solving the problem than the one is actually needed. This can be avoided by FEM.

FEM IN NANO-SCALE ANALYSIS AND DESIGN

However, how FEM can be implemented to approach a problem in nano-scale? The traditional finite elements are used to simulate structural members, structures or solids, which are modelled as continuum mediums. However, nanostructures and nano materials cannot actually be considered as continuums, due to their discrete nature. Hence, the direct utilization of traditional finite elements is not applicable, here. Since, in nano-scale, materials are characterized by a discrete geometry, they can be considered as frame-like structures, in which bonds and atoms play the role of the structural members and joints, respectively. Based on this concept, bonds' stiffness can be simulated by line-type finite elements, like beams[5], bars[6], truss elements[7], or springs[8-13]. Using the potential energy expressing the inter atomic interactions, the stiffness matrix of these finite elements can be determined, and, thus, the static or quasi-static mechanical response of nanostructures can be predicted. In this way, a large range of linear[14], non-linear [15] and stability[16,17] problems can be solved. Moreover, to simulate the dynamic behavior of a nanostructure, the modeling of inertial effects is required. The simplest way to achieve this is considering every atom as a lumped mass, and

thus, the corresponding mass matrix can be easily formulated. In this manner, another large range of dynamical problems, like as linear [18-20]and non-linear[21,22] vibrations can be approached.

Taking into account the effect of temperature on potential energy describing the inter atomic interactions, the influence of temperature on line-type finite element stiffness matrices can be calculated. Therefore, the thermo-mechanical behavior of nanostructures [23-25] can be also predicted by FEM! Furthermore, the range of the problem approached by FEM in nano-scale can be widened, introducing the electric performance of nanostructures into the mathematical models. For example, atomistic moment methods based on classical electrostatics can be utilized in order to evaluate the charge distribution in each nanostructure. Hence, properties such as electrostatic charge distributions, total charge and capacitance can be examined through parametric analyses [26]. Predicting also the corresponding electrostatics forces, the coupled electro-mechanical problem can be solved. By the above-mentioned approaches, it is clear that FEM is ready to be effectively implemented for the design of the future nano-devices [27,28], nano-machines[29,30] and nano-systems[31].

MULTI-SCALE MODELLING USING FEM

There are numerous applications, in which nanostructures and nanomaterials have to interact with traditional macro-scale materials. In such a case, the design problem has to be solved in multi-scales. When nano-technological design moves to larger scales, modelling of the problem fully in nano-scale using FEM or MD is not an effective methodology. Therefore, micro mechanical based methods linking nano-scale and continuum considerations should be proposed. The performance of multi-scale structures is greatly influenced by the interface, which has different properties from those of the macro-scale materials and the nano-scale material[32-39]. Generally, the three main mechanisms of interfacial load transfer are micromechanical interlocking, chemical bonding and the van der Waals interactions between the scales. The advantage of those hybrid methods is that they can utilize macroscopic properties in order to describe the macro-scale part of the structure and interface behavior. Detailed representation of the molecular nanostructure is avoided, making the formulations attractive and simultaneously, significant reductions in computational cost and complexity are achieved. This concept has been successfully implemented in the analysis and design of nano-composite structures. The experience has shown a remarkable modelling performance of those multi-scale FEMs in terms of accuracy and computational cost.

CONCLUSIONS

In conclusion, multi-scale FEMs and their applications in analysis and design can be proved efficient computational methods in the engineering design of advanced mechanical and aerospace structures and devices. Their accuracy and the significant reduction of the computational cost and model complexity make them an ideal design tool for scientists and engineers.

REFERENCES

1. *S. Iijima, Helical microtubules of graphitic carbon, Nature 354, Issue 6348(1991) 56-58.*
2. *K. S. Novoselov, A. K. Geim, S. Morozov, D. Jiang, M. Katsnelson, I. Grigorieva, ..., A. A. Firsov,. Two-dimensional gas of massless Diracfermions in graphene, Nature 438(7065) (2005)197.*
3. *Madou, M. J. (2002). Fundamentals of micro fabrication: the science of miniaturization. CRC press.*
4. *C. Li, T. W. Chou, A structural mechanics approach for the analysis of carbonnanotubes, International Journal of Solids and Structures 40(10) (2003) 2487-2499.*

5. *M. Arroyo, T. Belytschko , Finite crystal elasticity of carbon nanotubes based on the exponential Cauchy-Bornrule, Phys. Rev. B 69 (2004) 1-11.*
6. *Georgantzinos, S. K., Katsareas, D. E., & Anifantis, N. K. (2011). Graphene characterization: A fully non-linear spring-based finite element prediction. Physica E: Low-dimensional Systems and Nanostructures, 43(10), 1833-1839.*
7. *Tsiamaki, A. S., Giannopoulos, G. I., Georgantzinos, S. K., & Anifantis, N. K. (2017). Finite Element Modeling of Nanotubes. Carbon Nanotube-Reinforced Polymers: From Nanoscale to Macroscale, 291.*
8. *Sri, N., & Reddy, A. C. (2016). Formability of Elliptical SS304 Cups in Single Point Incremental Forming Process by Finite Element Method. International Journal of Research in Engineering & Technology, 4(11), 9-16*
9. *Alkhayatt, A. H. O., & Al-Haddad, G. M. H. (2016). Synthesis and structural characterization of sol-gel deposited fluorine doped nano crytalline cds thin films. International journal of research in applied, 4, 123-134.*
10. *Yang, J., Ke, L. L., &Kitipornchai, S. (2010). Nonlinear free vibration of single-walled carbon nanotubes using nonlocal Timoshenko beam theory. Physica E: Low-dimensional Systems and Nanostructures, 42(5), 1727-1735.*
11. *Malekzadeh, P., Haghighi, M. G., &Shojaee, M. (2014). Nonlinear free vibration of skew nanoplates with surface and small scale effects. Thin-Walled Structures, 78, 48-56.*
12. *Moore, M., Enomoto, A., Nakano, T., Egashira, R., Suda, T., Kayasuga, A., ... &Oiwa, K. (2006, March). A design of a molecular communication system for nano machines using molecular motors. In Pervasive Computing and Communications Workshops, 2006. PerCom Workshops 2006. Fourth Annual IEEE International Conference on (pp. 6-pp). IEEE.*
13. *Lozovik, Y. E., Minogin, A. V., &Popov, A. M. (2003). Nano machines based on carbonnanotubes. Physics Letters A, 313(1-2), 112-121.*
14. *Wang, Z. L. (2008). Towards self-powered nano systems: from nano generators to nano piezotronics. Advanced Functional Materials, 18(22), 3553-3567.*
15. *Georgantzinos, S. K., Giannopoulos, G. I., Spanos, K. N., & Anifantis, N. K. (2014). A Heterogeneous Discrete Approach of Interfacial Effects on Multi-Scale Modelling of Carbon Nanotube and Graphene Based Composites. In Modeling of Carbon Nanotubes, Graphene and their Composites (pp. 83-109). Springer, Cham.*
16. *Spanos, K. N., Georgantzinos, S. K., & Anifantis, N. K. (2014). Investigation of stress transfer in carbon nanotube reinforced composites using a multi-scale finite element approach. Composites Part B: Engineering, 63, 85-93.*